Description

Method and Control Circuit for Power Factor Correction

BACKGROUND OF INVENTION

[0001] This invention applies to the field of control of switching power converters and more particularly to the control of converters that absorb from their input voltage source a current that is directly proportional to the momentary value of voltage.

[0002] Converters operating in this fashion are often used to perform what is known as power factor correction.

[0003] *Prior art.*

[0004] US patents 5,804,950 and 6,307,361B1 show control methods for power factor correction converters that do not require sensing of the instantaneous value of the input voltage of the converter.

[0005] A common disadvantage of the control methods of the prior art is that loop gain of the control circuits is a square function of the input voltage.

[0006] This gain variation in conjunction with the need to limit the gain in order to achieve low harmonic distortions will adversely affect the dynamic performance of control circuits based on the algorithms of the prior art.

SUMMARY OF INVENTION

[0007] It is the goal of the present invention to create a simple method for a control circuit for power factor correction converters that does not require sensing of the instantaneous value of the input voltage of the converter, provides low harmonic distortions and good dynamic performance.

[0008] The present invention uses the output current of a power factor correction converter to provide the reference signal for Valley Current Mode control of its input current, thereby providing feed forward regulation of the output voltage against changes in the output load.

[0009] In addition, instead of operating the Valley Current Mode control circuit at the traditional fixed frequency, the frequency of operation is made directly proportional to the RMS or average value of the input voltage of the converter.

[0010] As a result, the dependence of the loop gain on the input voltage is significantly reduced and the dynamic performance of the converter is improved.

[0011] The gain compensation is achieved without the use of an

explicit divider.

[0012] For converter topologies with no direct access to the converter's input voltage, a signal directly proportional to the average or the peak of the input voltage peak value can be produced by sensing and rectifying the voltage that develops across an appropriate magnetic element during the conduction of the converter's switches.

[0013] Finally, complete correction for changes in the input voltage can be implemented by adding one division operation to the basic algorithm.

Brief Description of Drawings

[0014] Figure 1 shows a boost converter Power Factor Correction converter controlled by a Valley Current mode controller with load current feed forward

[0015] Figure 2 shows a boost derived Power Factor Correction converter controlled by a Valley Current mode controller with load current feed forward

[0016] Figure 3 shows a boost converter Power Factor Correction converter controlled by a Valley Current mode controller with load current feed forward and partial input voltage feed forward

[0017] Figure 4 shows a boost converter Power Factor Correction converter controlled by a Valley Current mode controller

with load current feed forward, partial input voltage feed forward and closed loop output voltage control

[0018] Figure 5 shows a boost converter Power Factor Correction converter controlled by a Valley Current mode controller with load current feed forward, full input voltage feed forward and closed loop output voltage control

[0019] Figure 6 shows a boost converter Power Factor Correction converter controlled by a Valley Current mode controller with load current feed forward, closed loop output voltage control and an equivalent embodiment of the full input voltage feed forward.

DETAILED DESCRIPTION

[0020] The operation of the control circuit will be described in conjunction with a boost converter (Fig. 1), consisting of boost inductor 1, power switch 2, output diode 3 and the output filter capacitor 4. The converter extracts power from a input voltage source 13 and delivers it to a load 14.

[0021] A current sensor 5 generates a signal directly proportional to the output current of the PFC converter. This signal is applied to V/I converter 6 that converts it to a current that charges capacitor 7 to create a saw tooth signal that is re-set every time a pulse from clock 8 turns switch 9 mo-

mentarily on.

[0022] Current sensor 12 generates a signal directly proportional to the input current. This signal is compared to the saw tooth signal by the PWM comparator 10. Comparator 10 sets the RS flip-flop 11 when the value of the current signal drops below the value of the ramp. Flip-flop 11 provides the drive for the power switch 2; in order to assure that no pulses are generated when the output current of the boost converter is near zero, an offset voltage 20 may be added to an input of comparator 10.

[0023] The timing pulses generated by clock 8 also reset flip-flop 11.

[0024] Comparator 10 and SR flip-flop 11 form a Valley Current Mode controller that, if the AC ripple current in inductor 1 is small compared to the instantaneous current, will cause the input current of the boost converter to be proportional to the momentary value of the input voltage 13 and to the amplitude of the saw tooth.

[0025] As the amplitude of the saw tooth is directly proportional to the output load current, the input current of the converter will be also directly proportional to its output current. This will cause the input power to track the output power, thereby regulating the output voltage against

changes caused by variation in the output load.

[0026] In some boost converter topologies that may be used for power factor correction, the input current is not readily accessible, but since the Valley Current Mode control requires current information only during the time the power switch(s) is OFF, the current flowing thorough the output diode(s) can be measured instead. An example of the present invention applied to such topology is shown in Fig. 2.

[0027] The proportionality between the momentary value of the input voltage and the input current is the basis for the capability of the boost converter controlled by the above circuit to provide power factor correction or, more accurately, allow the converter to draw power from the input voltage source without generating harmonics.

[0028] At the same time, this linear relationship between the input voltage and current will cause the average input power to increase as the square of the input voltage, causing the average output voltage to become proportional to the square of the half wave average or RMS ("long term") value of the input voltage.

[0029] It follows from the above that while proportionality between the momentary value of input voltage and current is

desirable and necessary for the purpose of power factor correction, the proportionality of the input current to the "long term" value of the input voltage has a severe detrimental effect on the line regulation of the output voltage and is therefore undesirable.

[0030] In one embodiment (Figure 3), the present invention mitigates this detrimental effect; another embodiment (Figure 5) eliminates it entirely.

[0031] Referring to Figure 3, a filter (block 16) receives the input voltage 13 and generates a signal proportional to the RMS or half wave average value of the input voltage. This signal is applied to a voltage to frequency converter 8 that generates the clock pulses.

[0032] As a result, the frequency of the clock will be proportional to RMS or half wave average value of the input voltage.

[0033] Since the input current of the converter is proportional to the amplitude of the saw tooth waveform appearing on capacitor 7 and this amplitude is inversely proportional to the clock frequency, the half wave average or RMS value of the input current of the converter will become independent of the RMS or half wave average value of the input voltage.

[0034] The result of controlling the converter according to this

algorithm is that its output voltage will be proportional to its input voltage.

[0035] The embodiment shown in Fig. 3 may be used as is (having the output voltage proportional to the input voltage may actually be desirable in some applications).

[0036] Adding a relatively slow acting close loop to the basic embodiment of Fig. 3 can regulate the output voltage (Figure 4).

[0037] An amplifier 15 compares the output voltage of the converter to reference 18 and generates a corrective signal that can be used to affect the duty cycle of the converter in order to regulate output voltage. In Fig. 4 common this signal is added to the input current signal generated by the current sensor 12. It would be apparent to those versed in the art that as the embodiment of Fig. 4 may actually be implemented with a variety of how long and/or digital means, it to my be more convenient to generate the corrective signal in different ways and to inject it a different in the circuit in order to obtain the desired regulation.

[0038] In the embodiment of Fig. 3, the open loop gain of the voltage regulation circuit varies linearly with the input voltage, so the compensation of loop is facilitated and the

dynamic performance is improved in comparison to the prior art control methods, for which the gain varies as the square of the input voltage.

[0039] It should be mentioned that in case of topologies (as the example of Figure 2) that do not provide direct access to the input voltage, a signal proportional to the average value of the input voltage can be synthesized by selective rectification and filtration of the pulsed voltage appearing on a winding placed on the equivalent of the boost inductor(s) (inductor 1 in Fig. 2) when the equivalent of the boost switch 2 is on (switches 2 and 2A in Fig. 2).

[0040] "Complete" input voltage feed forward correction can be accomplished by making the "long term" value of the input current of the converter inversely proportional to the "long term" value of the input voltage.

[0041] This is accomplished a by adding a division or multiplication operation to the embodiment of Fig. 4.

[0042] The preferred embodiment of the "complete" input voltage feed forward is shown in Fig. 5, where divider 21 divides the signal applied to the voltage to current converter 6 by the half wave average or RMS value of the input voltage produced by filter 16 (same functionality as filter 16 discussed previously).

[0043] An equivalent embodiment of the "complete" input voltage feed forward is shown in Figure 6, were multiplier 22 is used to multiply the signal generated by the current sensor 12 by the voltage produced by filter 16.

[0044] The "complete" feed forward correction may be used to further facilitate the compensation and improve the dynamic performance of the voltage control loop.